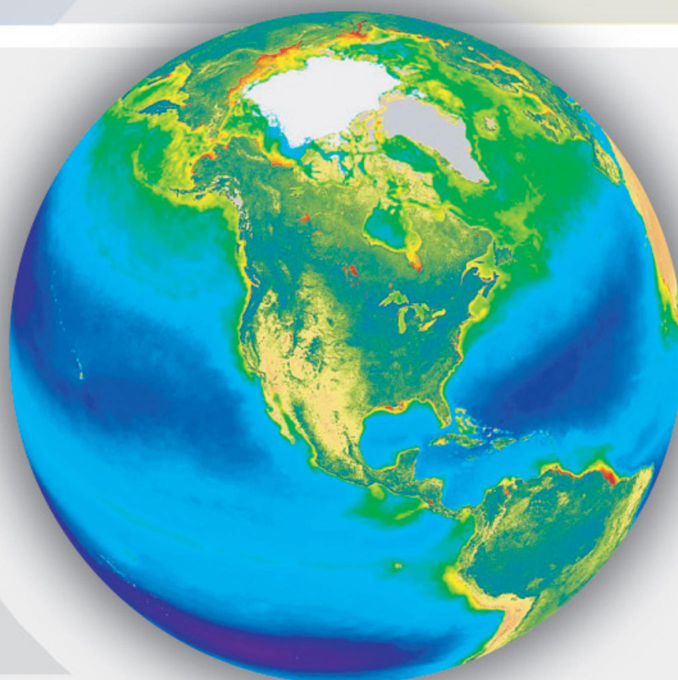
# 4 System Vicarious Calibration for PACE Mission



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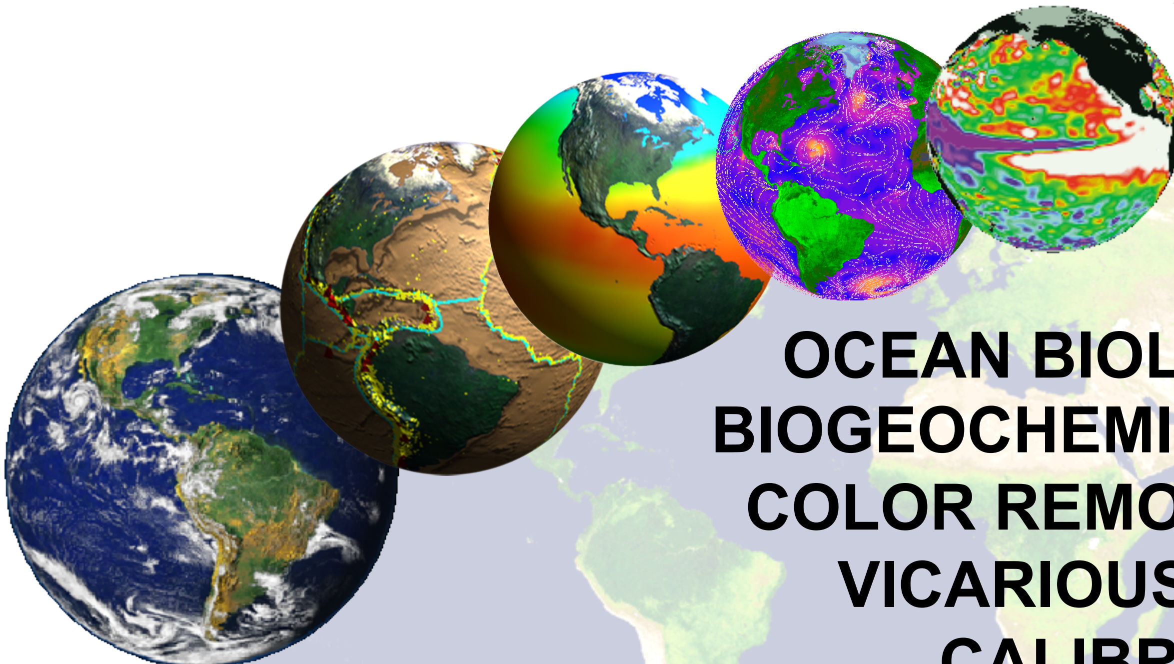
# ROSES 2014 Topic A.3



## OCEAN BIOLOGY AND BIOGEOCHEMISTRY: OCEAN COLOR REMOTE SENSING VICARIOUS (*IN SITU*) CALIBRATION INSTRUMENTS Panel

**NASA – SMD – ESD**
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**NASA Headquarters**
**12 August 2014**

# A.3: Ocean Biology and Biogeochemistry – Scope

- The Pre-Aerosol, Cloud, ocean Ecosystem (PACE) mission is a strategic Climate Continuity mission included in NASA's 2010 plan: Responding to the Challenge of Climate and Environmental Change: NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space (Climate Initiative - http://science.nasa.gov/earth-science/).

- Develop *in situ* vicarious calibration instruments, systems, and approaches for a future mission's ocean color instrument. "Vicarious" calibration - a final bias adjustment to the calibrated, spectral, top-of-atmosphere radiances observed by an ocean color instrument. Proposals should consider the PACE Science Definition Team (SDT) report (found at http://dsm.gsfc.nasa.gov/PACE.html); International Ocean Color Coordinating Group (IOCCG) report #13, Mission Requirements for Future Ocean-Colour Sensors (2012 - http://www.ioccg.org/reports_ioccg.html - Reports); IOCCG/Committee on Earth Observing Satellites Ocean Color Radiometry-Virtual Constellation white paper on the International Network for Sensor Inter-comparison and Uncertainty assessment for Ocean Color Radiometry (INSITU-OCR - http://www.ioccg.org/groups/INSITU-OCR_White-Paper.pdf); the "Systematic Observation Requirements for Satellite-Based Data Products for Climate 2011, Update Supplemental details to the satellite-based component of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)," World Meteorological Organization, Report GCOS – 154 , (2011).
- The deliverable - an *in situ* vicarious calibration capability for maintaining global climate quality ocean color remote sensing radiances and reflectances for a multi- or hyperspectral polar-orbiting ocean color sensor. Enable data records of essential climate variables.

# A.3: OBB - Background and Solicitation Justification

- The ocean is important for many reasons (ecology, economics, etc.).
- Ocean color sensor must have stringent calibration and validation (cal/val) data requirements for quantifying ocean color sensor performance, satisfying uncertainty requirements of the retrievals, and monitoring its stability over time. Future NASA ocean color science applications require highly accurate Rrs(λ) (spectral remote sensing reflectances). Highly accurate *in situ* measurements of Rrs(λ) will provide the principal source of surface truth for the operational vicarious calibration activity.
- Historically, ocean color retrievals benefitted from indirect calibrations of the satellite ocean color radiometer performed with respect to reference in situ measurements of Rrs(λ). This process is referred to as the "vicarious calibration" and, for heritage ocean color missions, as well as for current and future missions, it requires a dedicated calibration program.
- Open ocean location exhibiting: high spatial homogeneity (both for atmospheric and marine optical properties); high stability (within limits of seasonal changes); low cloudiness; known atmospheric-marine optical properties. For any given satellite-*in situ* $R_{rs}$ pair, different observation conditions (different viewing geometry, atmospheric and marine optical properties) become the source of uncertainties – need many paired observations so time series converges on single spectral vicarious calibration gain factors with uncertainty defined by target climate change applications of data products. Spectral gain factors are used to scale top of atmosphere (TOA) reflectances measured elsewhere (one goal - to minimize uncertainties in vicarious calibration gain factors within the first year of operations). Inclusion of additional observations (e.g., sun-photometer measurements) would be advised (for reasons that might include continuous site characterization or match-up exclusion criteria).

# A.3: OBB - Background and Solicitation Justification

- Once spectral sensor vicarious calibration gain factors are determined, the resultant calibrated global data set of TOA reflectances must then be corrected for local atmospheric conditions, and it is in this procedure (currently based on the near infrared - NIR - and short wave infrared - SWIR - approach) that errors can arise from uncertainties in aerosol optical properties. In addition, the magnitude and spectral properties of the aerosol optical depth (AOD) itself need to be taken into account to maximize accuracy of retrieved products..
- The shortest measurement band in most heritage ocean color has been near 410 nm. Uncertainties in atmospheric corrections generally increase with decreasing wavelength. Specifically, in the blue spectral region the aerosol amount, type, and vertical distribution may become the source of large uncertainties. For future ocean color missions, ocean retrievals could be extended into the near-ultraviolet (NUV) down to 350 nm. This extension may necessitate a reevaluation of the atmospheric correction approach due to difference in atmospheric optical properties between the UV and visible wavelengths (specifically, increased contribution from absorbing aerosols, as well as impacts of scattering aerosols).

# A.3: OBB - Background and Solicitation Justification

- The current requirement for calibration uncertainty of satellite ocean color sensors is less than 0.5% (with target value of 0.3%) in the blue-green spectral regions for oligotrophic-mesotrophic waters. This stringent value is justified by the high accuracy requirements established for utilizing satellite ocean color products in research operational investigations, most notably climate change investigations. Such a level of accuracy can be achieved with vicarious calibration: the adjustment of prelaunch calibration coefficients using top-of-atmosphere (TOA) radiance predicted from *in situ* measurements through modeling of atmospheric radiative processes (by applying the same models and codes used for the operational atmospheric correction process). In fact, as already anticipated, the objective of vicarious calibration is the minimization of combined uncertainties resulting from satellite absolute prelaunch calibration and from the specific models/algorithms applied for determining primary radiometric products (e.g., Rrs) from TOA radiance. Vicarious calibration should be performed using *in situ* radiometry ideally performed with dedicated systems (e.g., MOBY) ensuring a high degree of accuracy and with full traceability to SI (Système international d'unités) standards. The vicarious calibration site should be selected in a region where variability and complexity of the atmospheric and oceanic optical properties are low, to minimize additional sources of uncertainty due to temporal and spatial sampling differences between the satellite observation and the *in situ* measurement. Multiple vicarious calibration sites may offer additional information and alternative sources of data, however, these sites should be equivalent in terms of measurement accuracy, traceability, and observation conditions (e.g., different complexities of the atmosphere might lead to inaccurate determinations of the aerosol type and consequently to the determination of substantially different adjustment factors for the prelaunch calibration coefficients).

# A.3: OBB – Proposal Research Topics

- Robust vicarious calibration technologies and approaches. Requirement: a prelaunch absolute calibration with uncertainty lower than 2% and on-orbit absolute calibration uncertainty (before vicarious calibration) better than 5%. Current target for calibration uncertainty - below 0.5% (with target value of 0.3%) ensuring absolute radiometric uncertainty lower than 5% in Rrs satellite derived products in the blue-green spectral regions for oligotrophic-mesotrophic waters. Should also benefit from *in situ* remote sensing reflectance (Rrs) data for verifying postlaunch instrument gains. The recommended *in situ* vicarious calibration instrument(s) systems to support ocean color science applications shall provide an *in situ* vicarious calibration capability for maintaining global climate quality ocean color remote sensing radiances and reflectances for a multi- or hyperspectral polar-orbiting ocean color sensor:

1. Spectral range from 350-900 nm at < 3 nm resolution (ideally 1 nm),
2. Spectral radiometric uncertainty lower than 4% in the blue-green spectral region and of approximately 5% in the red, combining uncertainty contributions from instrument absolute calibration, characterization (including at least spectral calibration, nonlinearity, stray light perturbation and polarization sensitivity, temperature dependence and, if applicable, geometrical and in water response), environmental perturbation, and data processing (with National Institute for Standards and Technology - NIST - traceability),
3. Spectral radiometric stability of the order of 1% per deployment (with NIST traceability),
4. Capability of autonomous field operation,
5. Capable of maintaining its internal calibration throughout the three to five year mission,
6. In consideration of the entire life cycle of the instrument, the system shall be built with consideration to sustainability and field maintenance of the deployed system(s),
7. Fully laboratory and field characterized to all of the above requirements versus NIST standards prior to deployment, and
8. Fully autonomous in delivering the data, in proper format, fidelity, and latency, to enable the NASA mission science.

# A.3: OBB – Proposal Research Topics

- Additionally, it would be expected that complementary routine field efforts would also support any future satellite mission to verify data quality through the quantification of uncertainties affecting data products. Such fieldwork is not the subject of this solicitation.
- The proposed effort shall advance the Technology Readiness Level (TRL) of the proposed instrument. The required deliverable from this solicitation will be a fully tested, field deployable instrument at TRL 6 with the instrument ready to support a future mission with verified data quality and uncertainties sufficient for space product validation.
- International Principal Investigators (PIs) from institutions in countries outside the U.S. are free to propose to this solicitation on a no-exchange-of-funds basis. PIs from institutions outside the U.S., as interested, should indicate to the Points-of-Contact below their desire for participation.

# A.3: OBB – Programmatic Information

- Highlights (not comprehensive) - 2.1.2.2 Scientific/Technical/Management Section (Project Description)
  - This section must include the following content information in subsections that use the same titles. Failure to provide any of this material may be cause for the proposal being judged as noncompliant and returned without further review. The Project Description is limited to 15 nonreduced, single-spaced typewritten pages. Standard proposal style formats shall be in accordance with Section 2.2 of the Guidebook for Proposers. Proposals that exceed the 15-page limit will be truncated at 15 pages. PD Section shall include:
  - 1. A description of the existing capabilities and/or capabilities that need to be developed and how those capabilities would meet specified vicarious calibration instrument(s) requirement(s). Clearly state specific requirements that are being targeted, as well as any requirements that may not be fully met. Also, the proposers must clearly demonstrate an understanding of the full system life cycle from design through continued, prolonged operations in the field.
  - 2. A justification for why this particular capability or approach would meet the requirement (s).
  - 3. Comparative Instrument Assessment – Describe the anticipated advantages of this instrument and/or approach compared to those currently in use - e.g., reduction of size, mass, power, volume or cost, improved performance, or enabling of a new capability not previously possible. Reference the current state of the art and relate it to the proposed work.
  - 4. Technology Readiness Level (TRL) Assessment – Proposers must define the starting point for the instrument, system, or approach and the exit or success criteria for the proposed activity. It is required that the proposed system be TRL 6 and ready for deployment at the end of the funded development period. TRL definitions can be found at http://esto.nasa.gov/files/TRL.doc. The proposer shall identify the entry TRL, the planned exit TRL, and success criteria in their proposal. The proposer shall substantiate the entry TRL
  - 5. Research Management Plan – Must provide a statement of work that concisely describes each task and milestone to be accomplished in the course of the research and development. Define the success criteria associated with each task or milestone. Also include a schedule chart that identifies critical milestones. At least three milestones per twelve-month period must be defined. Subcontracting portions of research project is acceptable, overall management/reporting are responsibility of proposing organization.

# A.3: OBB – Programmatic Information

- Highlights (not comprehensive) - 2.1.2.2 Scientific/Technical/Management Section (Project Description)
  - 6. Personnel – Provide a list of key personnel and identify experience related to the proposed activity. Proposers should be sure to include science, technology development, and instrument development skills on the team. The key personnel list is included in the overall page count and must include, as a minimum, the Principal Investigator (PI). Optionally, one-page resumes for Key Personnel may be supplied; these resumes are not included in the 15-page limit for the Project Description Section.
  - 7. Facilities and Equipment – Describe significant facilities and equipment required to complete the work. Before requesting funding to purchase a major item of capital equipment, the proposer should determine if sharing or loan of equipment already available within the proposing organization is a feasible alternative.
  - 8. Special Matters –Should include brief description of organization, its facilities, previous work experience relevant to the proposal.
  - a. Funding profile shall contain an estimate of life cycle cost for the system, including projected field maintenance over the expected deployed life of the system.
  - 9. Quad Chart – Provide a summary chart (quad chart) that shall contain the following information:
  - • Upper Left Quadrant: "Description and Objectives"
  - • Lower Left Quadrant: "Approach" and "Co-Is/Partners"
  - • Upper Right Quadrant: A visual, graphic, or other pertinent information
  - • Lower Right Quadrant: "Milestone Schedule" and "Entry TRL."
  - A template and example of the quad chart can be downloaded from http://esto.nasa.gov/files/EntryQuad_instructions_template.ppt. Note: This quad chart is not included in 15-page limit for the Project Description Section.

# Selections

- In FY2014 NASA selected the following projects (US$10M/3 years):
  - Selection of an ocean color vicarious calibration approach and instrumentation competition through ROSES
    - Andrew Barnard/Western Environmental Technology Laboratories, Incorporated - *Hyperspectral Radiometric Device for Accurate Measurements of Water Leaving Radiance from Autonomous Platforms for Satellite Vicarious Calibrations*
    - Carlos Del Castillo/Goddard Space Flight Center - *Hybrid-Spectral Alternative for Remote Profiling of Optical Observations for NASA Satellites (HARPOONS)*
    - Kenneth Voss/University Of Miami, Coral Gables - *Developing a MOBY-NET Instrument, Suitable for a Federation Network for Vicarious Calibration of Ocean Color Satellites*

# Selections

- In FY2014 NASA selected the following projects (US$10M/3 years):
  - Andrew Barnard/Western Environmental Technology Laboratories, Incoporated - *Hyperspectral Radiometric Device for Accurate Measurements of Water Leaving Radiance from Autonomous Platforms for Satellite Vicarious Calibrations*
    - Equip Navis BGCi autonomous profiling float with newly developed hyperspectral radiometers + Chla, CDOM and backscattering sensors
    - Test data delivery system based on Iridium RUDICS telemetry.
    - Potential Development: a new hyper-spectral radiometer system targeting spectral resolution lower than 3nm; observations from 350 to 900 nm, and ensure high accuracy, precision and stability to measurements.
    - NIST role TBD (stray light characterization), Satlantic will characterize wavelength accuracy, linearity, polarization sensitivity, temperature dependent wavelength shift, and thermal responsivity.
    - Instruments will be integrated onto autonomous profiling floats for tests up to one year in blue waters to demonstrate autonomous operation and acquire profiles suitable for vicarious calibration (or potentially validation).
    - Goal - unattended operation over periods longer than three years in the open ocean. Field evaluations/validations planned at MOBY and BOUSSOLE.

# Selections

- In FY2014 NASA selected the following projects (US$10M/3 years):
  - Carlos Del Castillo/Goddard Space Flight Center - *Hybrid-Spectral Alternative for Remote Profiling of Optical Observations for NASA Satellites (HARPOONS)*
    - Investigates the suitability of a technologically-consolidated surface glider as a platform to support offshore radiometry measurements.
    - Integrating an optical profiler tethered to a Wave Glider autonomous vehicle.
    - Advance current spectral resolution of BioSpherical Inc. hybrid-spectral radiometers going to be operated on the Wave Glider (currently relying on MMS spectrometers) with more performing devices (relying on CGS spectrometers)
    - Integrate the advanced radiometer and the Wave Glider
    - Test the integrated system in Hawaii off Lanai and off the Southwest coast of Puerto Rico (proposed as new vicarious calibration site)

# Selections

- Kenneth Voss/University Of Miami, Coral Gables - *Developing a MOBY-NET Instrument, Suitable for a Federation Network for Vicarious Calibration of Ocean Color Satellites*
    - Upgrade the existing MOBY radiometric infrastructure with new modular, portable optical systems that can be easily shipped to/from calibration and deployment facilities (named MOBY-NET).
    - (1) a transportable optical system (to fit in a 40 ft shipping container);
    - (2) an extended spectral range to 350-900nm (from 370-900nm);
    - (3) a transportable source and stability monitor;
    - (4) simultaneously measured radiometric quantities (instead of sequential measurements);
    - (5) an enhanced UV anti-biofouling system; and,
    - (6) partnerships with commercial vendors to enable eventual network expansion.
    - Goal: design an instrument package to support a global network of MOBY-NET systems.
    - Network could be supported by local collaborators using identical optical systems with centralized and NIST traceable calibration and identical data reduction algorithms (think Aeronet and Aeronet-OC).
    - Two redundant systems will be developed and field tested (with a 3-mo deployment in 2017). Deployment periods of 4 months are anticipated but could be extended to 6 months after which instruments will be recalibrated with NIST traceability. Only the MOBY radiometric systems will be upgraded - the moored 3-arm MOBY platform concept will remain unchanged.